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This study compared castability values (Cv) in the Whitlock test with Cv obtained from a new castability monitor based on a dental restoration. Five metal ceramic casting alloys were induction cast with both a carbon-containing and a noncarbon phosphate-bonded casting investment to assess the reliability of the Whitlock mesh test in predicting alloy castability.

Alloy performance in the Whitlock test did not parallel that of the replica coping test for all alloy-investment pairs as would be anticipated for a reliable castability monitor. In addition, the variability of the Whitlock castability values for some alloys was sufficient to question its usefulness for "fine-tuning" the casting process with a specific alloy.

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A Comparison of Two Tests to Determine the Castability of Dental Alloys.

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ABSTRACT

A COMPARISON OF TWO TESTS FOR DETERMINING

THE CASTABILITY OF DENTAL ALLOYS

This study compared castability values (Cv) in the Whitlock test with Cv obtained from a new castability monitor based on a dental restoration. Five metal ceramic casting alloys were induction cast with both a carbon-containing and a noncarbon phosphate-bonded casting investment to assess the reliability of the Whitlock mesh test in predicting alloy castability.

Alloy performance in the Whitlock test did not parallel that of the replica coping test for all alloy-investment pairs as would be anticipated for a reliable castability monitor. In addition, the variability of the Whitlock castability values for some alloys was sufficient to question its usefulness for "fine-tuning" the casting process with a specific alloy.

Determining an appropriate method to measure the castability of dental alloys is difficult when dealing with different casting equipment (torch, electric, and induction) and alloys that vary markedly in composition and physical properties. The problem is compounded when the dental literature contains numerous reports of castability testing although the test methodology and test monitors (specimen configurations) differ widely.[1-46] Despite the absence of a recognized classification system, at least three types of castability tests exist. These categories are sufficiently distinct to warrant identification as: abstract tests (nondental patterns), simulation tests (patterns of idealized dental restorations), and replica tests (patterns of dental restorations).

Classification of Castability Tests

Abstract Tests

Test specimens which are neither simulations nor replicas of dental restorations may be classified as abstract patterns. The wide assortment of designs that have been created and proposed over the years include a blade or wedge, nylon lines supported by a solid bar, a spiral, a saucer, a sphere, a parallel-walled cylinder, a polyester nylon mesh with adjacent runner bars (Whitlock pattern), and modifications to the nylon mesh concept.[4-[illegible]] [illegible]ith abstract patterns castability is synonymous only with casting completeness, i.e., the ability to reproduce a pattern.

Simulation Tests

A major limitation of abstract castability monitors is the inability to measure both casting completeness and casting fit. This obstacle was overcome to some extent by the use of machined metal dies which simulate the configuration of prepared teeth. While the type of preparation (tooth and restoration selected, convergence angle, bevelled/nonbevelled etc.) varied, most of these studies evaluated castability in terms of casting accuracy and fit.[35-41]

Replica Tests

Despite the simplicity of abstract tests and the ease of fabrication of simulation tests, neither method duplicates the actual processing of dental casting alloys. The abstract patterns are far removed from dental restorations in terms of geometry, thickness, surface texture, etc. Simulation test patterns, on the other hand, are often too idealized and exact to reflect actual usage. Replica test patterns, however, are reproductions of restorations constructed on dies of actual preparations made on human or dentoform teeth.[3,42-44] Such designs more closely approximate or replicate the intended application of the alloys under study.

In 1981 Whitlock et al.[1] suggested the use of an abstract pattern in the form of an 18-gauge polyester mesh pattern as a simple means to obtain a castability value (Cv) and thus assess alloy castability. Hinman and others[2] later advised against using the Whitlock mesh test to compare different alloys and suggested it could best be applied to "fine-tune" the casting process for a given alloy. Despite this early concern for what was foreseen as a potential misapplication of the Whitlock test, the mesh pattern has been widely used in comparative castability studies.[24-34,45] Although the Whitlock specimens are relatively easy to fabricate and score, little information is available to demonstrate that the test itself, and all its subsequent variations, is a barometer of castability performance in the dental laboratory. Therefore, this investigation was undertaken to determine if the Whitlock test is a reliable monitor for castability and for "fine-tuning" the casting process when compared to a replica castability monitor.

Materials and Methods

The castability of five metal ceramic alloys of varying compositions (Olympia, J.F. Jelenko, Armonk, New York; Naturelle and Rexillium III, Jeneric/Pentron, Wallingford, Connecticut; Will-Ceram W1, Williams Dental Co, Amherst, New York; Forte, 3M/Unitek, St Paul, Minnesota) was compared with the Whitlock test and a replica test (Table 1). Both a carbon-containing phosphate-bonded investment (Ceramigold, Whip Mix Corp, Louisville, Kentucky) and a noncarbon phosphate-bonded investment (Vestra-fine, 3M/Unitek, St Paul, Minnesota) were used (Table 1). The

experiment was conducted in two parts. In Part I, five abstract (Whitlock) patterns were fabricated, invested in Ceramigold, and induction cast (Autocast, 3M/Unitek, St Paul, Minnesota). The process was repeated for five replica patterns with the same alloy later that day. The alloys were cast in the following order: Rexillium III, Forte, Will-Ceram W1, Naturelle, and Olympia. In Part II, the noncarbon phosphate investment Vestra-fine was used, but the order of text pattern preparation and casting remained the same. One hundred patterns were cast, five for each combination of test, investment, and alloy with the technique described in Table 2.

Initially a pilot study was undertaken to gain familiarity with specimen fabrication, to determine the amount of alloy needed per test, and to establish the most appropriate casting temperature and acceleration for each alloy (Table 1).

The original Whitlock polyester mesh pattern (Fig 1A) was modified slightly to eliminate sharp line angles, to insure a smooth flow of alloy to the pattern area, and to accommodate the oval ring and crucible former (Casting Oval System, Belle de St. Claire, Van Nuys, CA)(Fig 1B). Numerical castability values for the abstract mesh patterns were calculated, as recommended by Whitlock et al.[1] and Hinman and others.[2] The number of complete cast segments was totalled, divided by 220, and multiplied by 100 to obtain a percentage castability value (Cv). Three measurements of each casting were made by one individual (WPN) to insure correct and consistent scoring.

The replica castability test used a wax coping for an anterior metal ceramic crown substructure (Fig 2). A prepared dentoform tooth was reproduced in wax and cast in a base metal alloy (Rexillium III). The finish line was bevelled by hand to duplicate an actual preparation and the bevel dimensions were refined under a measuring microscope (Gaertner Scientific Corporation, Chicago, IL) until the following dimensions were achieved: mid-facial = 0.499 mm, mesial = .749 mm, distal = .750 mm, and mid-lingual = 1.004 mm. Impressions of the metal master die were made using a poly (vinyl siloxane) impression material (Perfourm, Columbus Dental Co., St. Louis, MO), and seven gypsum dies were produced with a Type IV high strength stone (Super Die, Whip Mix Corporation, Louisville, KY). Two extra dies were available in the event one of the five principal dies was

damaged. A metal ceramic wax pattern with a 10-gauge wax sprue former was reproduced by injection molding as described by Byrne et al.[3] Seventy wax replica test patterns were made, 50 for the experiment and 20 spares.

The marginal fit of each replica wax pattern was refined on its own die using 10X and 20X binocular magnification and oriented in the oval casting ring as shown in Fig 3. The investment for each pattern was individually vacuum mixed (Multivac 4, Degussa Dental Inc., New York, NY), and the casting rings placed in a humidor until the last one had set for a minimum of 1 hour. The five casting rings were burned out together and induction cast in the same order they were invested.

To insure the casting parameters were the same for both tests, the burnout furnace and casting machine control dials were fixed at the appropriate setting for each alloy until the five Whitlock and replica specimens had been cast.

Castability values of the replica patterns were determined by measuring the length of the midfacial, the two interproximal, and the midlingual bevels (Fig 4). After removing the sprues, the castings were placed in an index designed for each position that contained horizontal and vertical orientation lines. The amount of bevel cast was determined under the measuring microscope (Fig 5). An average of three measurements, measured to the nearest 0.001 mm, was obtained for all four of the selected measurement sites. The means of the four areas in each of the five castings were recorded and combined for the overall castability value (Cv) expressed as a percentage.

Replica castings representing the best and worst marginal areas, determined by examination with the binocular microscope, were viewed using scanning electron microscopy. Marginal sharpness, the level of pattern replication, and surface character were evaluated and photographed.

A two-way analysis of variance (ANOVA) of test versus alloy was performed for each investment using the combined castability values of all five alloys with the two castability tests. Then the data obtained for the individual castability values from the abstract (Whitlock) and the replica (coping) test were statistically analyzed with a one-way ANOVA. On the basis of the significant findings obtained, a Student-Newman-Keuls .oj offTest for variability was applied to the mean grouped data.

Results

The rank order and mean castability values for the five alloys in the abstract (Whitlock) test with Ceramigold investment (Part I) were: Rexillium III (100%), Naturelle (87.7%), Will-Ceram W1 (65.3%), Olympia (48.9%); and Forte (15.6%) (Table 3). For the Whitlock test with Vestra-fine investment (Part II) the results were: Rexillium III and Will-Ceram W1 (100%), Naturelle (99.4%), Olympia (85.8%), and Forte (25.0%) (Table 3 and Fig 6).

For the replica (coping) test and Ceramigold investment (Part I), four of the alloys cast more than 93% and three alloys reproduced more than 95% of the areas measured. The rank order and castability values were: Naturelle (96.9%), Rexillium III (96.4%), Olympia (95.3%), Will-Ceram W1 (93.5%), and Forte (63.2%) (Table 3 and Fig 7). The rank order and mean castability values using the replica test with Vestra-fine investment (Part II) were: Naturelle (97.8%), Will-Ceram W1 (95.9%), Forte (93.0%), Rexillium III (91.7%), and Olympia (88.2%) (Table 3).

When the castability values for all five alloys were averaged and the two tests compared by investment type, the differences between mean combined Cv were significantly different from one another (Table 4). With both Ceramigold and Vestra-fine, castability values were higher with the replica (coping) test.

When a carbon-containing phosphate-bonded investment was used (Part I) the castability values for all five alloys differed significantly in the Whitlock test whereas only Forte differed significantly in the coping test (Tables 3 and 5 and Fig 6). When a noncarbon phosphate-bonded investment was used (Part II), Rexillium III, W-1, and Naturelle were not statistically different from one another in the Whitlock test, but Olympia and Forte were significantly different from one another and from Rexillium III, Will-Ceram W1, and Naturelle (Tables 3 and 6). With the replica test and Vestra-fine investment, alloy performance was more closely grouped and overlap was evident (Tables 5 and 6, Fig 7). While Will-Ceram W1, Forte, and Rexillium III did not differ significantly in performance, Naturelle and Olympia did, with Naturelle attaining the highest castability value (97.8%) of the five alloys (Table 3).

In Part I of the study, only the performance of Rexillium III in the Whitlock test (Cv 100%) approximated its level of castability in the replica test, Cv - 96.4% (Fig 6). For the remaining four alloys the Whitlock Cv ranged from 9.2% to 47 6% below the corresponding castability value with the replica test. In Part II, Naturelle, Olympia, and Will-Ceram W1 had comparable abstract/replica castability values (within 4.1%) while Rexillium III had a 8.3% higher Cv with the mesh test and Forte a 68% lower castability value as compared to the coping test.

The castability values of the two tests were within 1.6% to 4.1% of one another for the following four alloy-investment pairs: Rexillium III and Ceramigold, Will-Ceram W1 and Vestra-fine, Naturelle and Vestra-fine, and Olympia and Vestra-fine (Table 3). In the remaining six pairs, the differences between mean abstract (Whitlock) and replica (coping) Cv ranged from 8.3% (Rexillium III and Vestra-fine) to 68% (Forte and Vestra-fine). Consequently, the amount of mesh reproduced in the Whitlock test did not directly correspond to the length of bevel cast in the coping test (Fig 8).

Furthermore, the variability in castability values was greater among the five consecutive abstract test specimens than those in the replica (coping) test. For example, Whitlock castability values for Will-Ceram W1 with Ceramigold ranged from 53.2% to 85.5%, a 32.3% difference between the five consecutive castings (Fig 9). The shape of the cast Whitlock specimens differed for alloys reproducing less than 100% of the mesh pattern. Such a finding indicated that variations existed in the mold filling of different alloys and even the same alloy cast several times (Fig 9).[47] On the other hand, no replica test scores differed by more than 11.9% (Forte with Vestra-fine), and some varied by as little as 2.9% (Will-Ceram W1 with Vestra-fine).

Certain subjective observations were also made during the study and are worthy of mention. First, prolonged burnout (1 3/4 hours) at high temperature (1600° F) appeared to eliminate carbon from Ceramigold investment, as recommended for palladium-, nickel- and cobalt-based alloys. However, a substantial amount of carbon remained in this investment at temperatures between 1300 and 1500° F, despite the lengthy heat-soaking time (Fig 10). Second, although their castability values were lower, castings made in Ceramigold appeared to be smoother than those produced in Vestra-fine at the burnout and casting temperatures used in this study. Third, four of the five Olympia

replica test patterns cast in Ceramigold had suck-back porosity, and the fifth contained pin-point porosity in the same area.

Discussion

Castability in the abstract (Whitlock) test was measured as a percentage of the mesh pattern reproduced, while in the replica (coping) test it was the amount of bevel cast. The results of this study indicated that performance on the Whitlock test does not correlate with (i.e., predict) the castability results of the replica test. Although the combined mean castability values were significantly higher in the replica test than those in the abstract test (Table 4), not all alloys had higher Cv in the replica test (Table 3).

Furthermore, it appeared that investment selection can affect Whitlock castability values more than the replica test Cv. For example, castability values between investments for the Whitlock test differed for four of the five alloys. Except for Rexillium III (Cv - 100%), the remaining four alloys improved their Whitlock Cv merely by switching from Ceramigold to Vestra-fine investment. Most notably, Olympia increased its castability value by 36.9%, from 48.9 to 85.8%, with the noncarbon investment yet the castings were rougher than with Ceramigold (Fig 6). This observation further substantiates the sensitivity of the mesh test to investment selection. Conversely, with the replica test, three of the five alloys had Cv within 0.9% to 4.7% of one another even when the investment was changed (Naturelle - 0.9%, W-1 - 2.4%, and Rexillium III - 4.7%), and another alloy had a Cv within 7.1% (Olympia)(Fig 7). However, Forte had a 29.8% Cv increase with Vestra-fine. The results for this nickel-chromium beryllium-free alloy are not surprising as alloys of this type often do not perform in castability tests at the same level as nickel-based alloys containing beryllium.[48]

There was no minimum Whitlock Cv for any of the five alloys with either investment that would indicate an acceptable threshold limit or target Cv as judged from the replica test. Since Rexillium III reproduced 100% of the Whitlock pattern with both investments but never more than an average 96.4% of the replica patterns, a Whitlock test of this design may not discriminate between alloys capable of reproducing the entire pattern. In other words, based on the Whitlock test results, the

casting par··· .eters (casting temperature, acceleration, etc.) could be considered ideal, whereas the replica test scores would suggest some margin of improvement was possible. Whitlock test results indicated the casting parameters for Forte with Vestra-fine were extremely poor (Cv - 25%). Yet, the castability value for the replica test conducted the same day with the same casting parameters was 93%.

Given the potential interspecimen variability in the Whitlock test (Fig. 9), its utility for "fine-tuning" the casting process remains in question. Conclusions from castability studies using a mesh castability monitor might be influenced by this variability if the number of castings per alloy is small.

Because the Whitlock test relies on an abstract specimen design, it is not possible to assess both casting fit and castability. However, a replica test based on a metal ceramic crown substructure can be modified to evaluate casting fit merely by returning the castings to their stone or master metal die for measurement. The special liquid to distilled water or the liquid to powder ratios can be adjusted along with other casting parameters until both castability <u>and</u> casting fit are deemed acceptable. The replica test castability scores can easily be converted to a millimeter or micrometer measurement representing the amount of bevel that was <u>not</u> cast for a given area irrespective of the type of alloy (Table 6). Such information provides an evaluator with meaningful measurements (in millimeters or micrometers) of a casting discrepancy. No comparable conclusion can be made with the Whitlock pattern.

Despite higher castability scores in both tests with Vestra-fine investment, a comparison of the scanning electron micrographs revealed that the surface of copings cast in Ceramigold appeared denser with more uniform margins (Fig 11A). The castings made with Vestra-fine reproduced wax detail, including what appeared to be slight marginal overextensions not noted with Ceramigold replica patterns (Fig 11B). This suggested that casting parameters, such as casting and burnout temperature, should be established for each individual alloy-investment pairing rather than using the same settings for every alloy and investment.

Carbon elimination could only be assured with prolonged heat-soaking (1 3/4 hours) at 1600 °F and not in the 1300 to 1500° F range (Fig. 10). It would appear that carbon elimination is more temperature dependent than time dependent. Since carbon exposure is potentially more harmful to palladium-, nickel-, and cobalt-based metals, it may be prudent to use a noncarbon phosphate-bonded investments with these alloys.

No explanation is offered to account for the suck-back porosity[49] that occurred in the Olympia replica specimens cast in Ceramigold. Even though the casting parameters were the same for Olympia cast in Vestra-fine, no suck-back porosity was seen with replica specimens in that group.

It must be emphasized that the casting of dental alloys is a multifactorial process of enormous complexity with variables that are readily altered when substituting different alloys, investments, and casting equipment. Consequently, generalizations outside the confines of specific castability tests may not be germane to other alloys of similar composition or different casting equipment unless evaluated under comparable test conditions. Pilot studies are strongly recommended and may prove helpful to operators unfamiliar with the handling characteristics of the dental alloys, equipment, and materials they have chosen to evaluate.

Conclusions

1. Castability values determined by the abstract (Whitlock) test did not correlate with the values obtained when a replica (coping) test pattern of a metal ceramic substructure was used.

2. The rank order of performance and mean castability values (Cv) for the Whitlock test with Ceramigold were: Rexillium III (100%), Naturelle (87.7%), Will-Ceram W1 (65.3%), Olympia (48.9%), and Forte (15.6%); and for Vestra-fine the results were: Rexillium III and Will-Ceram W1 (100%), Naturelle (99.4%), Olympia (85.8%), and Forte (25.0%).

3. The rank order of performance and mean castability values for the replica test with Ceramigold were: Naturelle (96.9%), Rexillium III (96.4%),Olympia (95.3%), Will-Ceram W1 (93.5%), and Forte 63.2%; and for Vestra-fine, the results were Natu ie (97.8%), Will-Ceram W1 (95.9%), Forte (93.0%), Rexillium III (91.7%), and Olympia (88.2%).

4. With Ceramigold investment, only Rexillium III had approximately the same level of castability with both castability monitors. Whitlock castability values for the remaining four alloys were 9.2% to 47.6% below their corresponding replica Cv. With Vestra-fine investment Olympia and Will-Ceram W1 had comparable Whitlock and replica Cv (within 4.1%) while Rexillium III had an 8.3% <u>higher</u> Cv with the mesh test and Forte a 68% <u>lower</u> castability value compared to the replica test.

5. Replica patterns cast in Ceramigold were denser and had more uniform margins than similar patterns cast in Vestra-fine.

6. Investment selection has a greater impact on castability values in the Whitlock test than the replica (coping) test.

7. No minimum castability value (Cv) appeared to exist for the Whitlock test which would predict a complete cast dental restoration.

8. Castability values among specimens within alloy-investment pairs varied more with the Whitlock test than the replica test, rendering the mesh test a less than reliable indicator of alloy castability. Consequently, the value of the Whitlock test as a monitor for "fine-tuning" the casting process is questionable.

9. Carbon elimination for phosphate-bonded investments is more <u>temperature</u> dependent than time dependent.

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Table 1 Alloys and Casting Parameters.

Alloy	Composition (%)	Mold Temp (^{O}F)	Cast Temp (^{O}F)	Soak Time (sec)	Acceleration
Rexillium III	Ni-74-78 Cr-12-15 Be-1.8	1600	2925	5	7.0
Forte	Ni-64 Cr-22 Mb-9	1500	2950	0	7.0
Will-Ceram W1	Pd-53.5 Ag-37.5 Sn-8.5	1550	2650	0	5.5
Naturelle	Pd-79 Cu-10 Ga-9 Au-2	1500	2850	5	5.5
Olympia	Au-51.5 Pd-38.5 Ga-1.5	1300	2925	0	5.5

* The burnout temperatures and heat-soaking times are those recommended by the alloy manufacturers. The remaining parameters were established in the pilot study.

TABLE 2 Description of Technique.

Mesh Test Pattern	
Dimensions:	No. 18 gauge polyester sieve cloth with 10 x 10 square segments
Runner Bars:	10-gauge round wax
Sprue Former:	10 mm 6-gauge round wax
Experimental Test Pattern	
Configuration:	Single unit anterior metal ceramic crown substructure
Sprue Former:	6-gauge round wax
Investing and Burnout	
Ring:	Belle de St. Claire Oval Ring (53.5 mm long, 28 mm wide)
Ring Liner:	Ceramic (Belle de St. Claire)
Mixing Conditions:	100% special liquid for Ceramigold and Vestra-fine, 1 min vacuum mix at 375 RPM and 30-sec hold under vacuum
Setting Conditions:	One hour in a humidor
Burnout:	Two-stage technique, 600°C 30 min then 1-3/4 hr heat-soak at high temperature
Casting Technique	
Amount of Alloy:	Base metal alloys - 2 ingots; noble metal alloys - 5 dwt
Machine:	Unitek Autocast, induction melting
Temperature:	Olympia and Rexillium III-2925° F; Forte-2950° F; Will-Ceram W1-2650° F; Naturelle-2850° F
Crucible:	Quartz (heated)
Casting Ring Orientation:	Vertical

TABLE 3 Castability Values* for Each Test-Alloy Combination with the Two Investments.

	Rexillium III	Forte	Will-Ceram W1	Naturelle	Olympia
Whitlock Test					
Part I					
Ceramigold	100.0 (0.0)	15.6 (4.5)	65.3 (13.5)	87.7 (6.0)	48.9 (10.1)
Part II					
Vestra-fine	100.0 (0.0)	25.0 (5.6)	100.0 (0.0)	99.4 (0.89)	85.8 (5.3)
Replica Test					
Part I					
Ceramigold	96.4 (1.8)	63.2 (4.4)	93.5 (4.3)	96.9 (1.6)	95.3 (3.4)
Part II					
Vestra-fine	91.7 (3.8)	93.0 (5.1)	95.9 (1.2)	97.8 (1.4)	88.2 (2.7)

* Mean and (Standard Deviation), n = 5.

Table 4 Analysis of Variance of Castability Tests by Type of Investment.

Ceramigold Investment		Vestra-fine Investment	
Test	Mean Combined Cv	Test	Mean Combined Cv
Replica (Coping)	89.1%	Replica (Coping)	93.3%
Abstract (Whitlock)	63.5%	Abstract (Whitlock)	82.0%

The combined castability values of the five alloys with the two castability tests are significantly different at $P \leq 0.05$ (Student-Newman-Keuls test) for both types of investment.

Table 5 Statistical Analysis of Alloy Castability with the Abstract (Whitlock) Test by Investment Type.

Ceramigold Investment		Vestra-fine Investment	
Rexillium III	100%	Rexillium III	100%
Naturelle	87.7%	Will-Ceram W1	100%
Will-Ceram W1	65.3%	Naturelle	99.4%
Olympia	48.9%	Olympia	85.8%
Forte	15.6%	Forte	25.0%

Alloys connected with a vertical line are not significantly different at $P \leq 0.05$ (Student-Newman-Keul's test).

Table 6 Statistical Analysis of Alloy Castability with the Replica (Coping) Test by Investment Type.

Ceramigold Investment		Vestra-fine Investment	
Naturelle	96.9%	Naturelle	97.8%
Rexillium III	96.4%	Will-Ceram W1	95.9%
Olympia	95.3%	Forte	93.0%
Will-Ceram W1	93.5%	Rexillium III	91.7%
Forte	63.2%	Olympia	88.2%

Alloys connected with a vertical line are not significantly different at $P \leq 0.05$ (Student-Newman-Keul's test).

TABLE 7 COMPARISON OF CASTABILITY VALUES (Cv) AND THE PORTION OF THE BEVELLED AREAS NOT REPRODUCED IN THE REPLICA TEST

Castability Value (Cv)	Facial Margin (0.499mm)	Mesial Margin (0.749mm)	Distal Margin (0.750mm)	Lingual Margin (1.004mm)
99%	0.005	0.007	0.008	0.010
98%	0.010	0.015	0.105	0.020
97%	0.015	0.022	0.023	0.030
96%	0.020	0.030	0.030	0.040
95%	0.025	0.037	0.038	0.050
94%	0.030	0.045	0.045	0.060
93%	0.035	0.052	0.053	0.070
92%	0.040	0.060	0.060	0.080
91%	0.045	0.067	0.068	0.090
90%	0.050	0.075	0.075	0.100
89%	0.055	0.082	0.083	0.110
88%	0.060	0.090	0.090	0.120
85%	0.075	0.112	0.113	0.151
82%	0.090	0.135	0.135	0.181
80%	0.100	0.150	0.150	0.201
75%	0.125	0.187	0.188	0.251
69%	0.155	0.232	0.233	0.311
60%	0.200	0.300	0.300	0.402

Conversion (1.0 mm = 1000 μm): 0.010 mm = 10 μm
0.100 mm = 100 μm

LEGENDS

Figure 1. Design of the original Whitlock mesh pattern (A) and the modified Whitlock pattern used in this experiment (B).

Figure 2. Drawing of the master die with a circumferential bevel (A) and the master wax pattern (B).

Figure 3. Configuration of the replica (coping) pattern invested in the oval ring.

Figure 4. For the replica test, castability represents the amount of the margin area (A) reproduced in the casting (B). The lingual bevel has been used as an example.

Figure 5. Cross hair positions for measuring bevel length as viewed through the measuring microscope.

Figure 6. The percentage castability values (Cv) for the five alloys with the two investments in the abstract (Whitlock) test.

Figure 7. The percentage castability values (Cv) for the five alloys with the two investments in the replica (coping) test.

Figure 8. The amount of mesh cast in the Whitlock test (left) did not always correspond to the amount of bevel reproduced in the replica (coping) test (right).

Figure 9. The shape of the five Whitlock specimens for W-1 cast in Ceramigold varied and castability values (B) ranged from 53.2% (left) to 85.5% (right).

Figure 10. Carbon is not completely eliminated from the investment despite 1 3/4 hours heat-soaking at 1500° F. Note the reduced oxide formation in the carbon-containing area on this W-1 casting.

Figure 11. SEM comparison of the facial margin of Rexillium III replica (coping) specimens cast in Ceramigold (A) and Vestra-fine (B) (orig.mag.200X).

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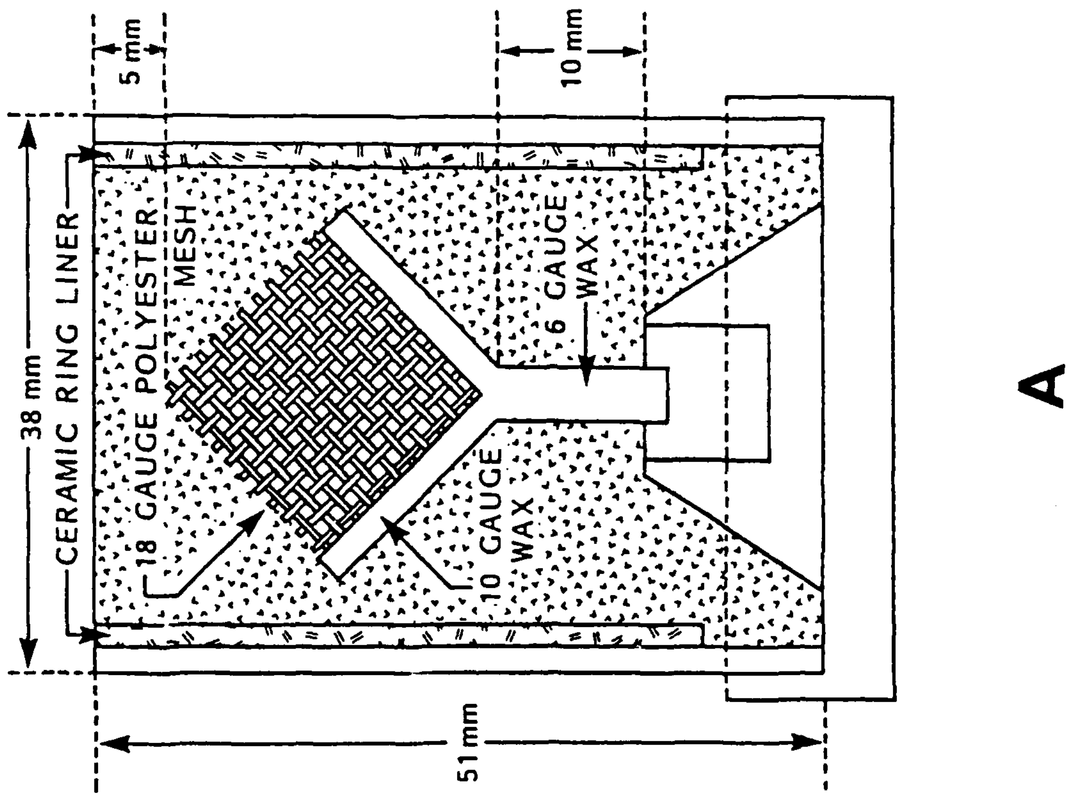
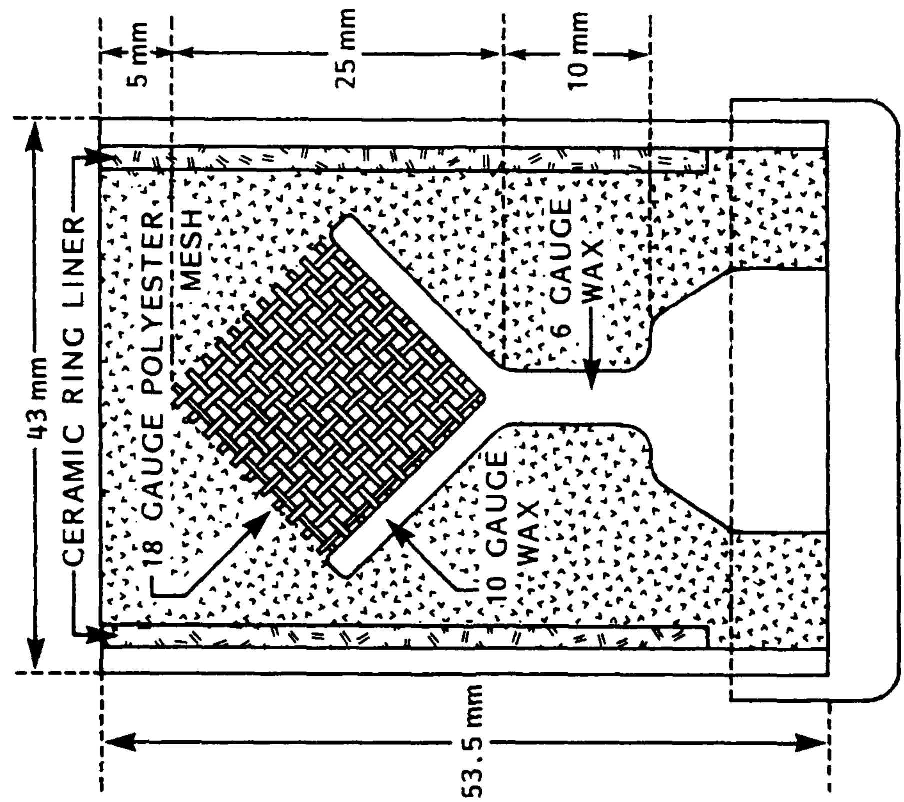

CERAMIC RING LINER
38 mm
18 GAUGE POLYESTER MESH
10 GAUGE WAX
6 GAUGE WAX
5 mm
10 mm
51 mm
A

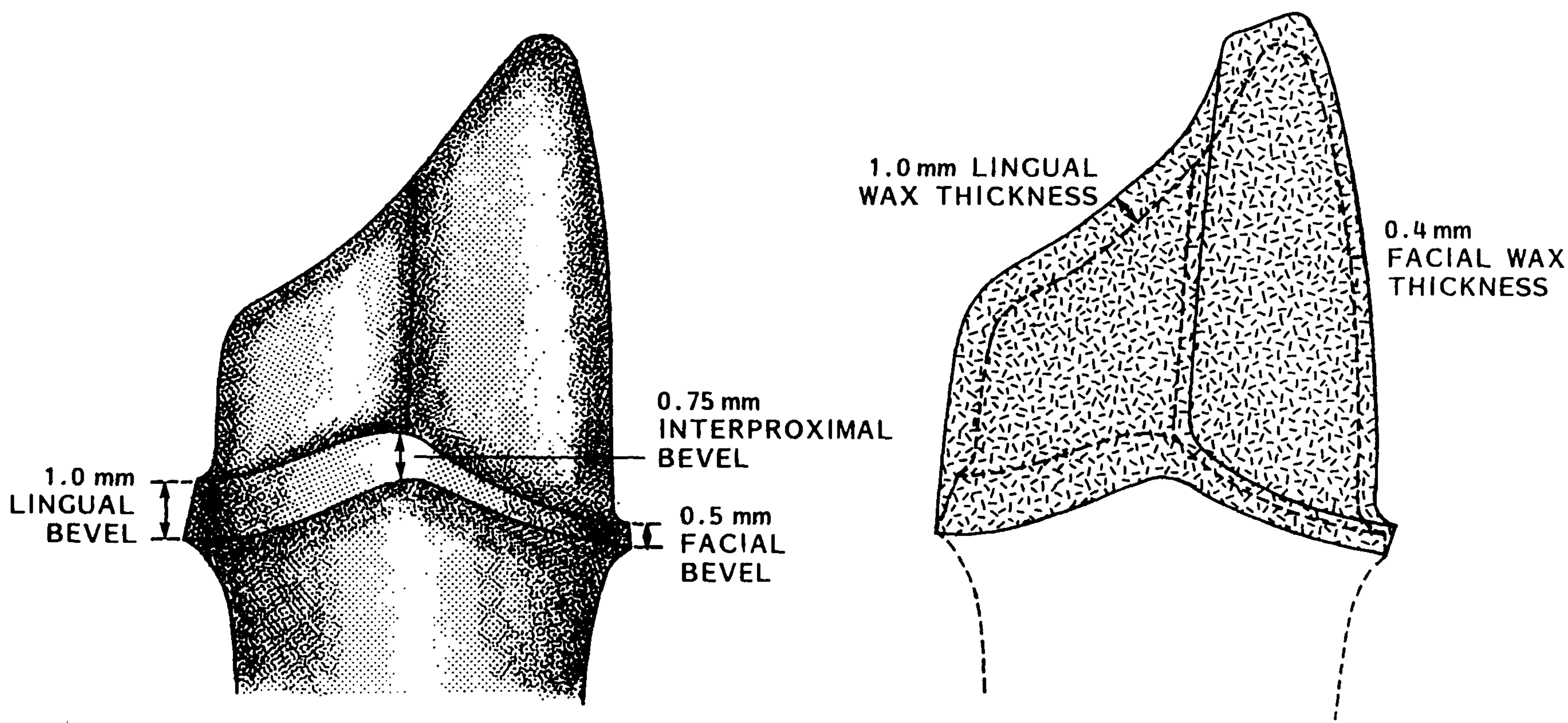
Fig. 1A



5 mm
25 mm
10 mm
43 mm
CERAMIC RING LINER
18 GAUGE POLYESTER MESH
6 GAUGE WAX
10 GAUGE WAX
53.5 mm

B

Fig. 1B



MASTER DIE CONFIGURATION

A

MASTER WAX PATTERN CONFIGURATION

B

Fig. 2

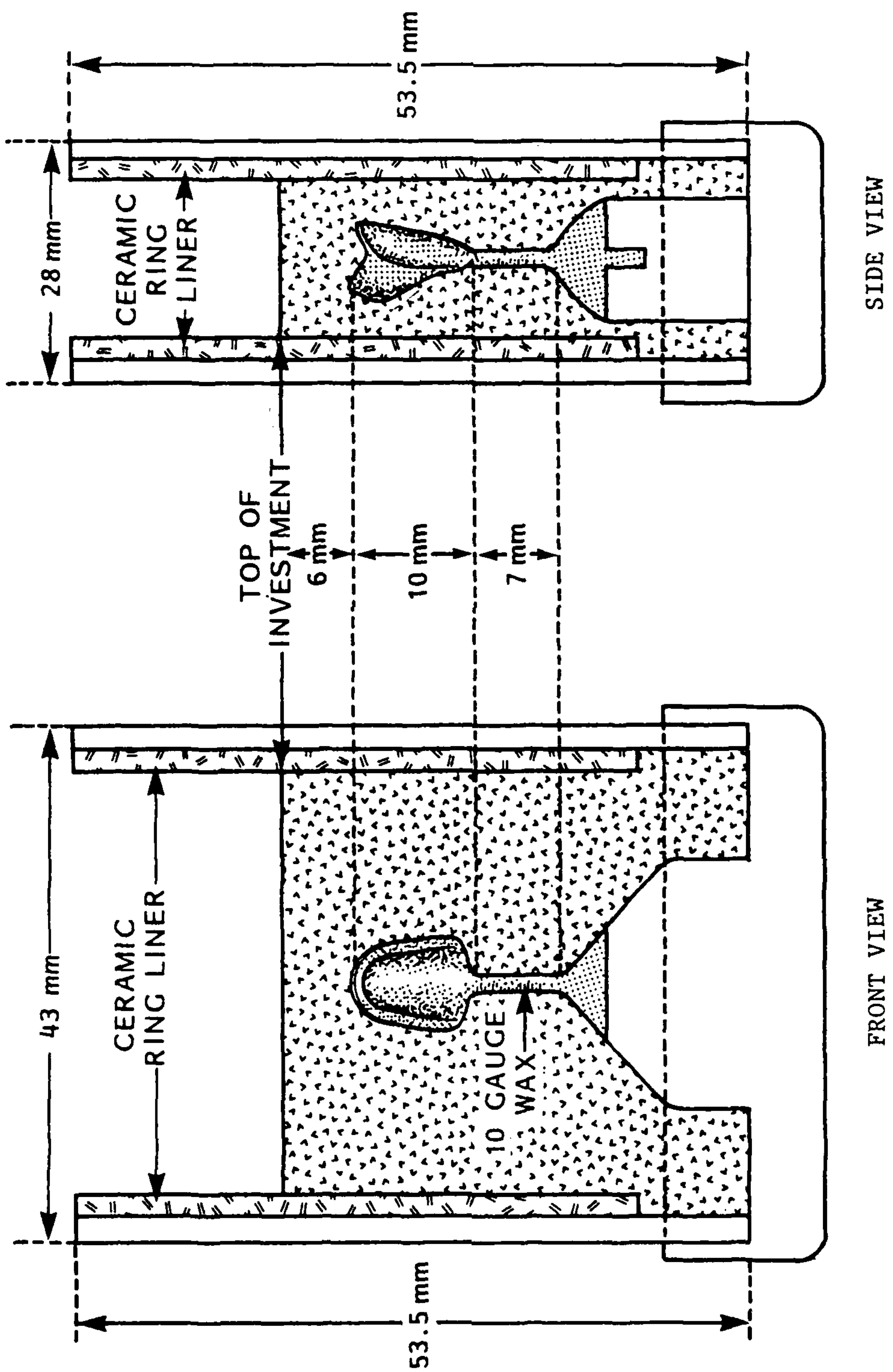

53.5 mm
28 mm
CERAMIC
RING
LINER
SIDE VIEW
TOP OF
INVESTMENT
6 mm
10 mm
7 mm
43 mm
CERAMIC
RING LINER
10 GAUGE
WAX
FRONT VIEW
53.5 mm

Fig. 3

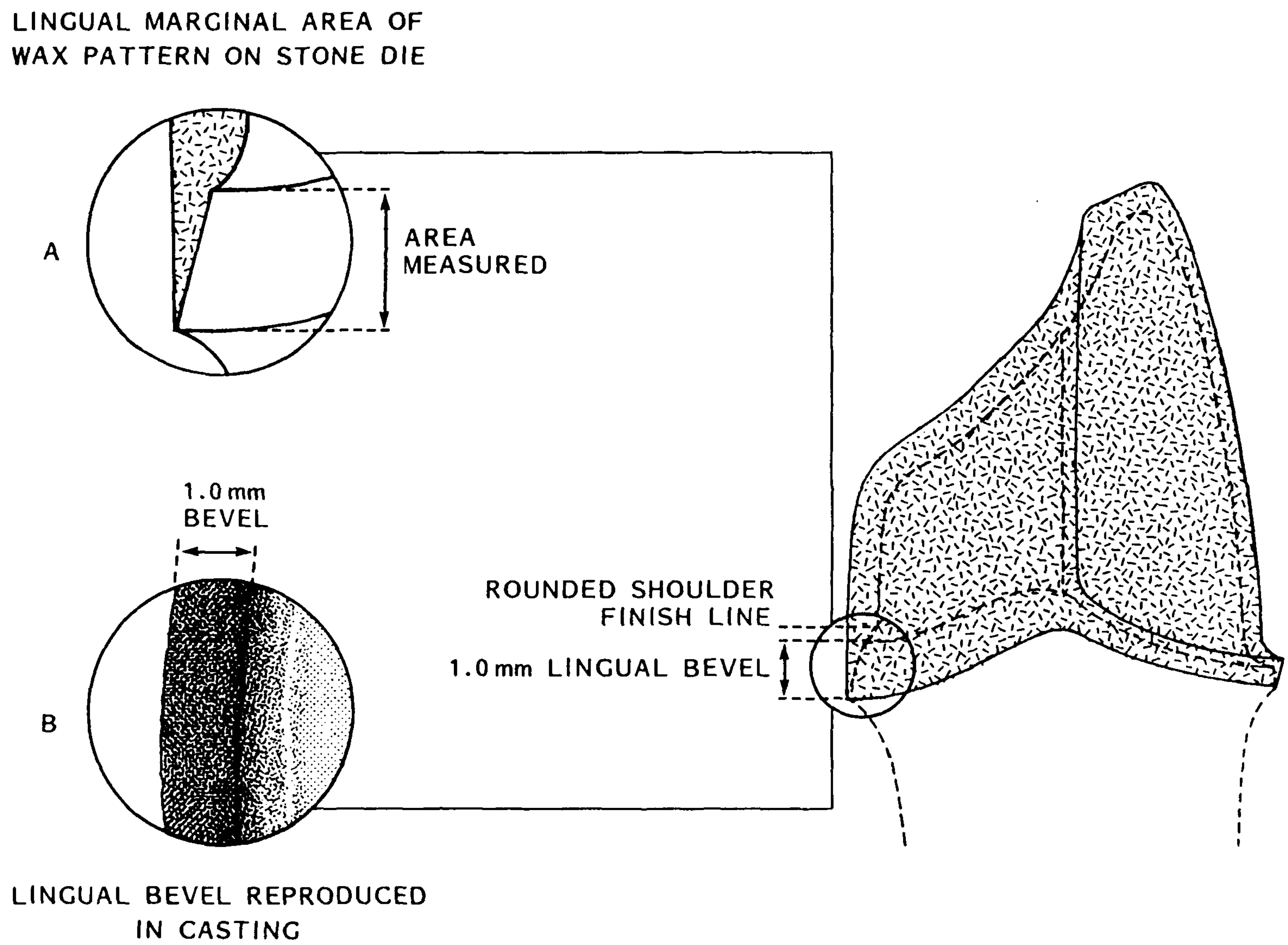
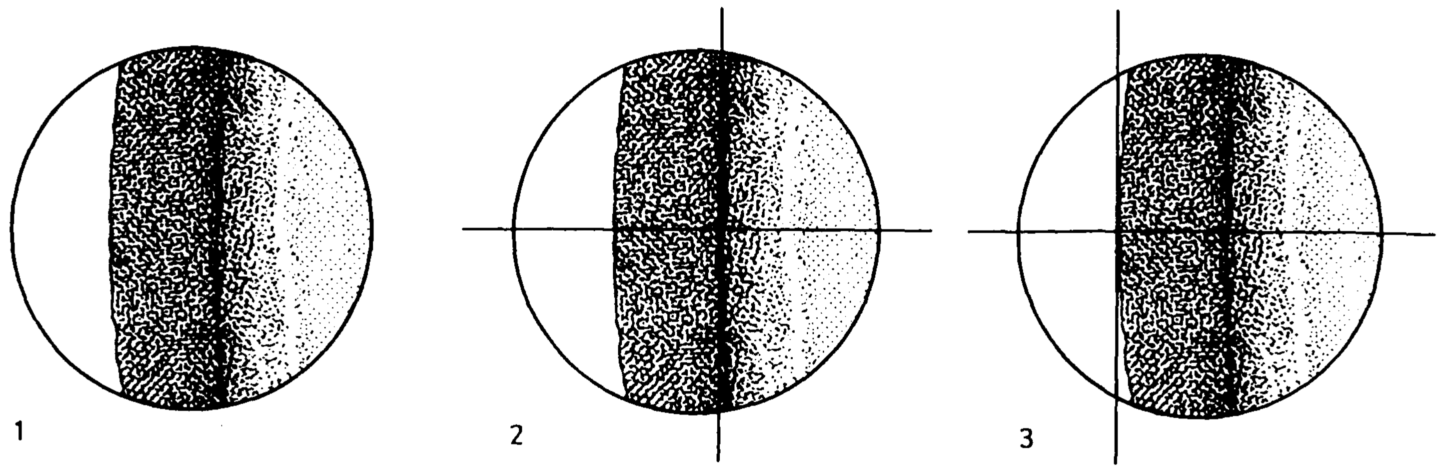

LINGUAL MARGINAL AREA OF
WAX PATTERN ON STONE DIE
A
AREA
MEASURED
1.0 mm
BEVEL
B
LINGUAL BEVEL REPRODUCED
IN CASTING
ROUNDED SHOULDER
FINISH LINE
1.0 mm LINGUAL BEVEL

Fig. 4



CROSS HAIR POSITIONS FOR MEASURING BEVEL LENGTH
ON MEASURING MICROSCOPE

Fig. 5

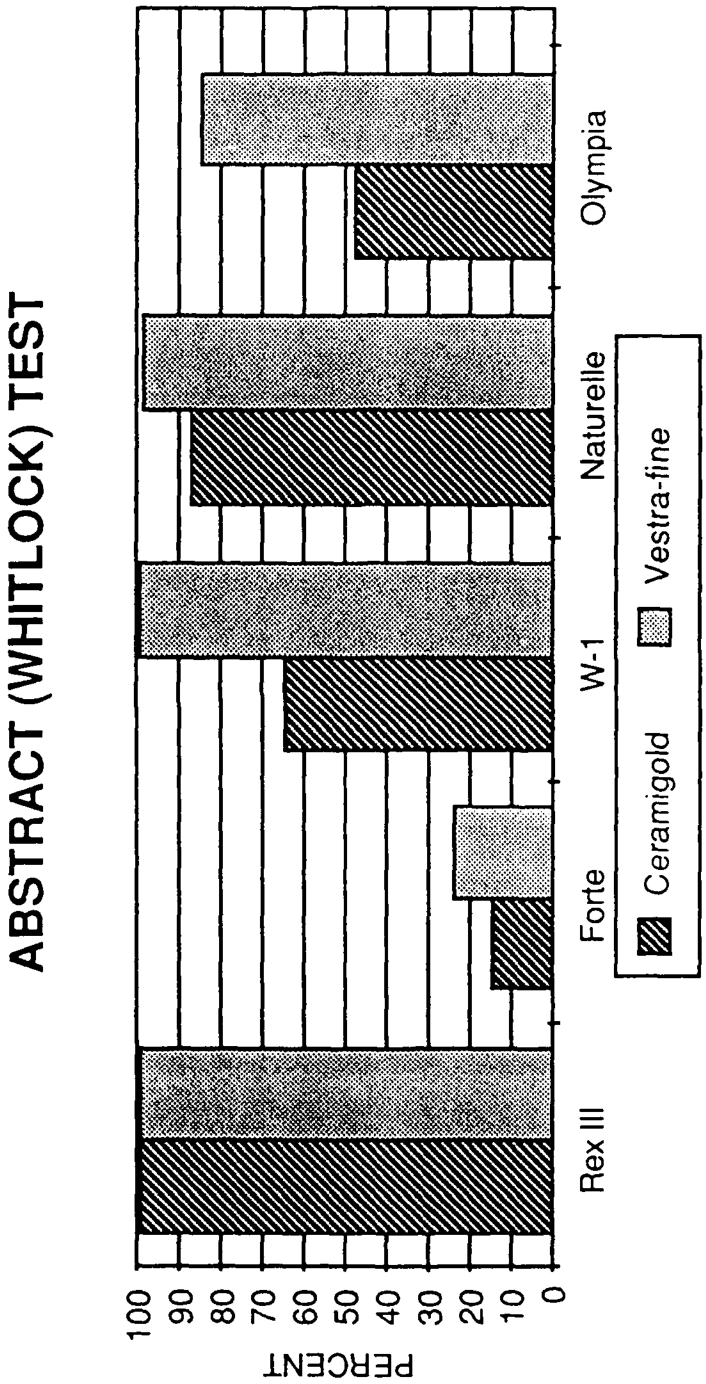

ABSTRACT (WHITLOCK) TEST
PERCENT
100
90
80
70
60
50
40
30
20
10
0
Rex III
Forte
W-1
Naturelle
Olympia
Ceramigold
Vestra-fine

Fig. 6

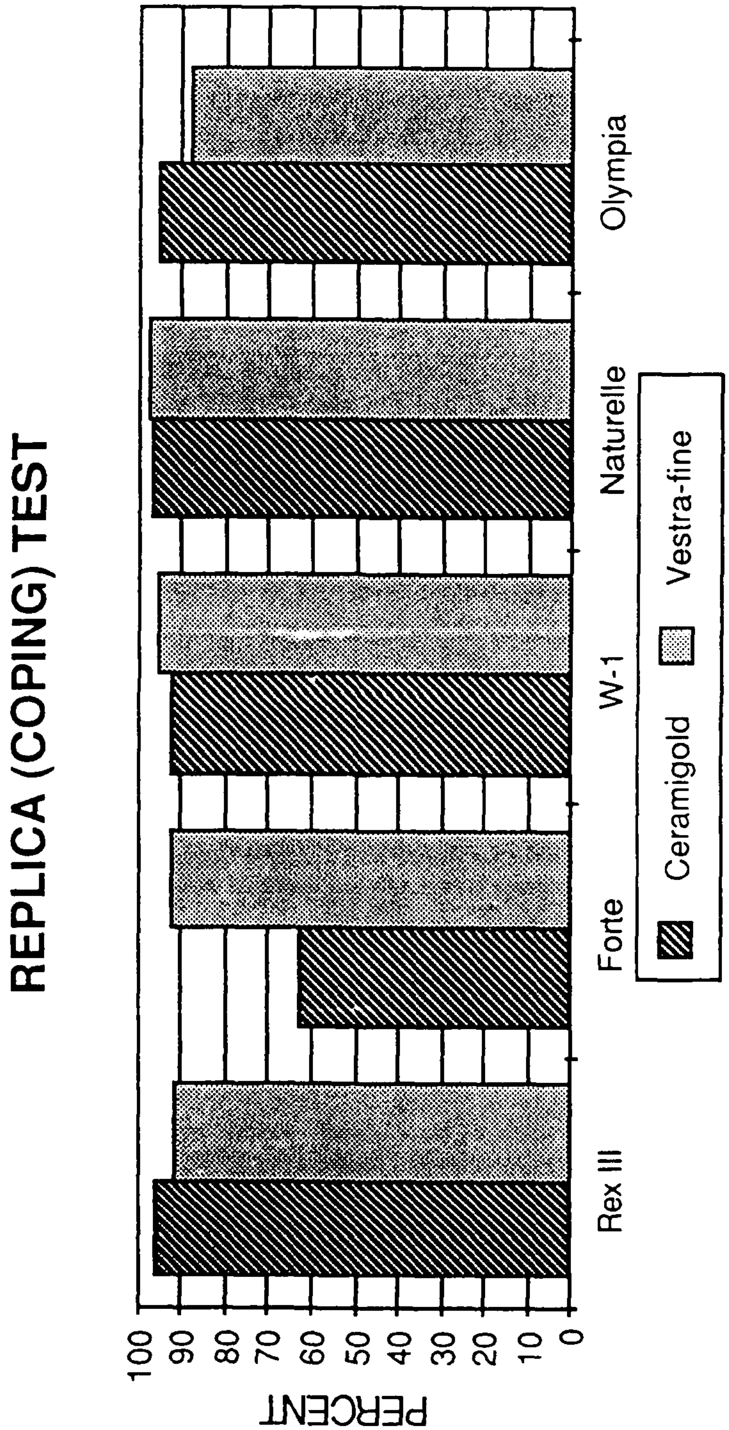

REPLICA (COPING) TEST
PERCENT
100
90
80
70
60
50
40
30
20
10
0
Rex III
Forte
W-1
Naturelle
Olympia
Ceramigold
Vestra-fine

Fig. 7

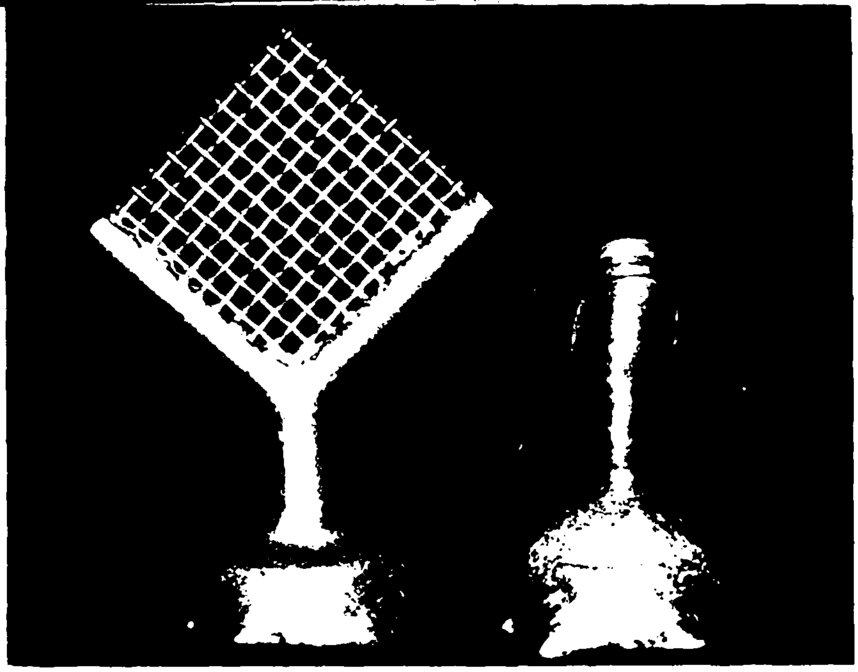


Fig. 8

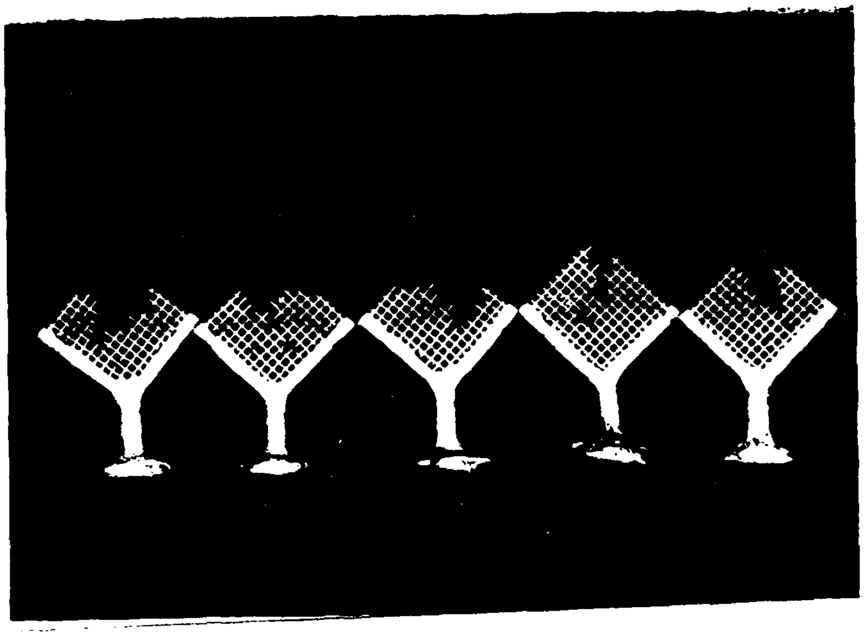


Fig. 9A

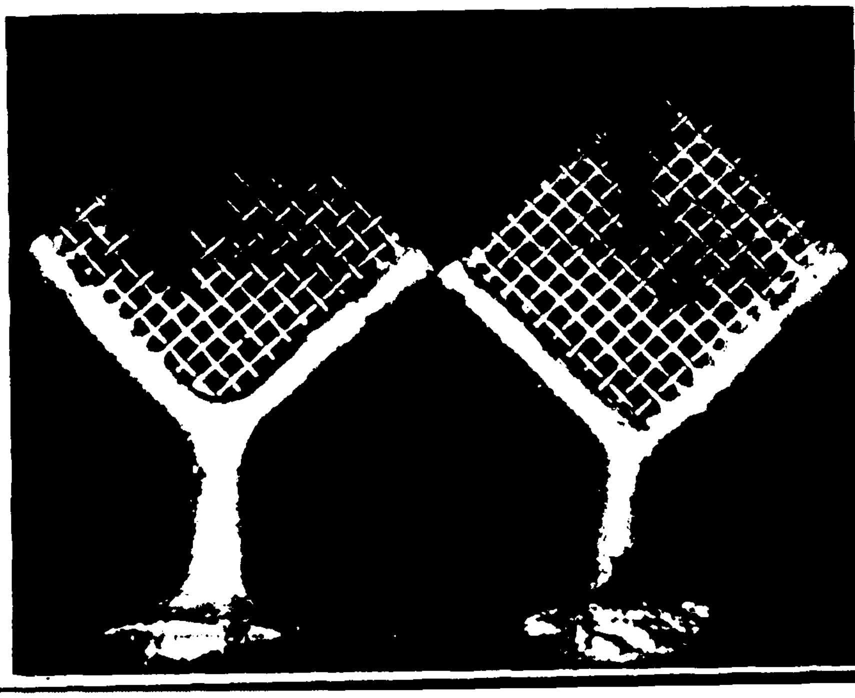


Fig. 9B

Fig. 10

Fig. 11A

Fig. 11 B